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Attitudes and aspirations regarding engineering among Chinese secondary school students: Comparisons between industrialising and post-industrial geo-engineering regions of Mainland China and Hong Kong[1]

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Attitudes and aspirations regarding engineering among Chinese secondary school students

Abstract

School-based pipelines for university and technical engineering education are recognised as important for economic development and the high-school years are critical for shaping students' career aspirations and attitudes. This study examined a range of attitudes/experiences on the aspirations of secondary students to pursue engineering education and vocation. Experiential/attitudinal aspects covered demographic characteristics, family/school support, practical learning experiences, curricular/extra-curricular experiences, attitudes, perceptions and engineering-efficacy that may affect aspirations. A validated questionnaire capturing these variables was administered to respective samples of secondary school students from four Chinese geo-engineering regions (Beijing, Guangzhou, Hong Kong and ShanXi; 5965 students) that represent differing degrees of industrialisation. Comparative analyses across regions show 'doing' engineering is key to motivating students' aspirations; while regional variations suggest that schooling and family factors are generally more significant in industrialising Mainland cities, and extracurricular opportunities and personal factors are more significant for students in post-industrial Hong Kong.

Key words: Engineering education, Secondary schools, Industrialising/post-industrial, China, Attitudes, Efficacy

Attitudes and aspirations regarding engineering among Chinese secondary school students

Introduction

The need to inspire future engineers to enter school-based pipelines that provide inspiration and training for engineers has been acknowledged in industrialising and post-industrial countries (Borrego and Bernhard 2011; Brophy, Klein, Portsmore and Roger 2008; Katehi, Pearson and Feder 2009; OECD 2010). This study focuses on the secondary school pipeline in China – a country that demonstrates extremes of engineering development. The special administrative of Hong Kong (hereafter HK) has been identified as the most advanced post-industrial society and Mainland China as one of the world's fastest growing industrialising societies (Wei 2005). Both parts of China acknowledge the need to develop students' interest and uptake of careers in engineering within schooling (MoE China 2012; HK Education Bureau 2016) and its crucial role in economic development (Xie, Zhang and Lai 2014). Students in both parts of China score at the highest levels in international comparisons of mathematics and science - the bases for engineering (Mullis, Martin, Foy and Arora 2012; OECD 2010). In order to understand how schooling may affect entry into/maintenance of the engineering pipeline, researchers need to develop insight based on students' experiences and opportunities, engagement, motivation, social support and feelings of engineering efficacy (Lucas, Cooper, Ward and Cave 2009). In exploring these effects of schooling, experience and culture, it would be naïve to assume that a single sample can characterise students' experiences, engagement, efficacy, etc. within China – especially as it is known that the Mainland experiences high demand for engineers and high student uptake into engineering careers while HK experiences high demand but has only modest student uptake.

Background

Before describing how Chinese schooling may inspire students into the engineering pipeline, we provide a broad consideration of aspects and processes of engineering education (especially provided in secondary schooling). The notion of pipeline is used to explain a perceived route into engineering (Silim and Crosse 2014) supported via cultural and (especially) school experiences wherein younger students' initially positive attitudes and perceptions of engineering may 'leak' away by the time that they make career choices. Internationally, there are few school-provided courses or programmes for the direct study of engineering and limited research on this topic. In place of engineering, other STM (science, technology, mathematics) subjects are taught throughout junior and senior secondary schools - although engineering experiences have been recommended to take place as early as possible in schooling (Borrego and Bernhard 2011; Capobianco, French and Diefes-Dux 2012; Guzey, Tank, Wang, Roehrig and Moore 2014; Unfried, Faber and Wiebe 2014; Wang and Degol 2013). Schooling contexts may be seen to discourage students' engineering aspirations, for example: the teaching pedagogy underlying engineering and STM courses tends to be formal–theory and teacher-dominated (Lyons 2006). Teachers who present engineering to students often have little background or practical understanding of engineering (Katehi et al. 2009). Most school-based engineering studies tend to focus on the relationship between teachers' knowledge and students' attitudes to engineering (Lewis, 2007; Nathan, Tran, Atwood, Prevost, and Phelps 2010); although Ajzen (1991) notes a poor relationship exists between attitudes and (student) choices for further study/career. In place of these attitudinal-based explanations a number of researchers have drawn from Bandura's (1997) focus on domain-specific findings of (engineering) efficacy and actual experience of engineering that may take place inside/outside formal schooling (Lucas et al. 2009; Wang and Degol 2013).

We further draw upon a broader STM literature which has identified that students are likely to make future education/career choices at earlier rather than later stages of their secondary schooling (Osborne and Archer 2007). Their choices are likely to be affected by actual/authentic experiences (Wang and Degol 2013; Lucas et al. 2009) provided by within-school and extracurricular experiences. Social support is important, whether it comes from parents/close relatives, teachers and peers (Godwin, Potvin and Hazari 2014; Guzey et al. 2014). A relatively new concept of STEM Capital (from ASPIRES 2013) amalgamates social support with authentic experience within the student's culture and has been associated with positive attitudes and aspirations for future careers. Attempts to draw together theory-based factors allied to students who have become an engineer acknowledge that the STEM "pathway is composed of a series of choices and achievements that commence in childhood and adolescence" and affected by "cultural norms, behaviour, social experiences, aptitudes and affective reactions to previous experience" (Wang and Degol 2013, p.305). The STM literature has also identified where potential leakages in the pipeline may be attributed. The ROSE study (Sjøberg and Schreiner 2005) identified a negative correlation between science career aspirations and placement on the United Nations Human Development Index (UNHDI) as well as gendered attitudes towards science. Technology teachers often lack domain-specific pedagogic knowledge and confidence to actively engage their students (Rohaan, Ruurd and Wim 2010). Yet Osborne, Simon & Collins' (2003) review of science education suggests that schools can offer more pipeline support for students. Similar to the

PATT studies (Rohaan et al. 2010) students should be more actively engaged and in control of their science/technology learning via practical work, investigations and reflection. Osborne et al. explain that this greater engagement will should enhance student 'value' of the subject, expectancy-value identity (Eccles and Wigfield 2002) and social cognitive careers (Lent, Brown, Hackett 1994).

STEM-based identity and careers theory generally draw upon individual student attitudes and perceptions. Yet, the STEM literature also acknowledges that career aspirations are based on students' feelings of domain-specific (engineering) efficacy which are affected by culturally-based norms and expectations as advanced in Ajzen's (1991) theory of planned behaviour. In order to compare students' aspirations for engineering-based further study/careers across China, we must be able to draw upon and integrate a diversity of (engineering) information (Wang and Degol 2013) that is likely to include aspects of their demographic background, social/cultural support, motivation, perception, experience and efficacy (Lucas et al. 2009).

STEM development in Mainland China

China has been aware of the importance of STEM from its earliest days (Zhu and Jesiek 2014). China is the second largest investor in (engineering-based) research and development (Hong 2015; Oleksiyenko 2014; Liu, Liang and Lui 2012). It has the largest number of/highest proportion (41%) of students studying STEM subjects in tertiary education (Hong 2015; Zhu 2013). Sciences and related STEM topics have been taught in Chinese primary and secondary schools since 1904 (Liu et al. 2012). Its pedagogic approach has been theory/teacher-dominated until 2000 - often characterised as based on China's Confucian Heritage [CHC] (Biggs 1996). From 2000, the STEM curriculum was revised to an integrated approach facilitated by an inquiry–based pedagogy. Technology is integrated into the science curriculum, and school visits provide experience of science applications in society (Wei and Thomas 2007). Curriculum elements have been adapted from the Soviet Union (in the 1950s) and Western countries (from 2000) to support China's pragmatic need for science and engineering (Wan, Wong and Yung 2011; Yu and Hu 2015). All primary and secondary students are required to study science subjects even if they are specialising in arts subjects in upper secondary school (Gao 2013; Wei and Thomas 2007). All lower secondary students also study information, engineering and labour technology while upper secondary students study general (including electronic and domestic; *Tongyong jishu kecheng*) technology and social practice (Ding 2009; MoE China 2001; Yu and Hu 2015). Both labour technology and social practice engage students in out-of-school organisations and work experience.

Chinese educators have also realised that the range of industrialisation throughout the country requires local and regional applications of science and engineering. To exemplify differences between the 31 Mainland regions, we focus on three areas. These areas are distinct in terms of engineering focus and general economic well-being. 2016 per capita income was (World Economic Database 2016): Beijing – US$17099 (the 2nd ranking province); Guangzhou – US$10838 (ranking 8th); and ShanXi – US$5606 (ranking 27th). Each of these regions requires a distinct geo-engineering focus (Lui et al. 2012): Beijing requires engineers to work/develop services, manufacturing and construction; Guangzhou requires electrical/electronic engineers and international trade specialists; and ShanXi requires engineers oriented towards metal ore mining, energy production and chemical manufacturing. While the literature has identified the need for STEM students (especially engineers) in China, there has been little or no information of how participation in this effective engineering/STEM pipeline affects school-aged students in China and its regions. China has not been involved in the ROSE or PATT studies and given its range/divergence of regional development, it may be naïve to assume that a single representative sample of students' engineering aspirations could characterise the country.

STEM education in HK and the Mainland

Although a semi-autonomous region of China, HK contrasts with the Mainland. It is one of the most advanced post-industrial countries (Wei, 2005) with 2016 per capita income of US$42963 (Statisticstimes 2017) and strong financial, trading and construction engineering sectors. HK and China are ranked separately on the United Nations Human Development Index of 188 countries (UNDP 2017: HK 12th and China 90th). In both Mainland China and HK school attainment is characterised in high stakes testing. Teaching/pedagogic methods were characterised by teacher/theory domination and pupil passivity (Biggs 1996), although these methods have been recommended to change towards more pupil involvement via inquiry-based pedagogies (Chow 2011; Liu et al. 2012). Students in both regions score at the very highest levels in international testing for science and mathematics (Mullis et al. 2012; OECD 2010). The importance of engineering for national and regional development has been acknowledged in HK and the Mainland (HK Education Bureau 2016; MoE China 2012); realising that schooling is one of the main forces to promote economic development. Within compulsory schooling, students are introduced to science, mathematics and technology; engineering is not a formal curriculum topic and rarely offered until upper secondary schooling.

Within HK, there has been greater emphasis on mathematics than science in primary school (Inoue 2013). In the Mainland mathematics and sciences receive equal emphasis (Chow 2011). And, while there is a stated importance in prioritising STEM subjects in HK (HK Education Bureau 2016) aspects of engineering and technology only account for 8% of the secondary school curriculum (Sin 2007). There appears to be a much higher proportion of STEM subjects and curriculum time in the Mainland where over 30% of secondary school credits are based on STEM subjects (Gao 2013). From this background, it appears that there is greater chance of an effective STEM pipeline in the Mainland than HK. To support the point, we identify: a) 41% of Mainland Bachelor's degrees are in STEM subjects (Hong 2015); b) engineers accounted for 34% of all undergraduate entries in China for 2015 (MoE China 2016); c) while engineering/applied engineering only accounted for 15% of 2015 undergraduate entries in HK (JUPAS 2015).

The limited literature has identified similarities and differences with regard to those choosing to study engineering/STEM subjects across China. Both HK and the Mainland have espoused the need for engineers and identified the school system as the main vehicle to introduce potential engineering aspirations to its students. Yet, there are distinct differences in effectiveness of the school-based pipeline for future engineers between industrialising and post-industrial regions of China. Understanding why these differences exist may be attributed to limited distinctions between school systems but is more likely to be found in the effects of schooling and culture on secondary school students. Currently, there is a dearth of studies of attitudes, understanding of and interest in engineering among school-aged students in China. Using a focused survey and selecting distinct geo-engineering regions of China, this study draws upon student demographic information, their engineering experience (curricular and extra-curricular), perception of engineers, engineering efficacy and aspirations to become an engineer, and asks the following research questions:

1. Are there engineering-based experiential, attitudinal, perceptual, efficacy and aspirational differences among Mainland secondary school students with regard to familial experience of engineering, age and sex of students and type of school attended?

2. Are there engineering-based experiential, attitudinal, perceptual, efficacy and aspirational differences among secondary school students between high-earning, post-industrial HK and the industrialising Mainland?; and

3. Are there engineering-based experiential, attitudinal, perceptual, efficacy and aspirational differences among secondary school students between diverse geo-engineering regions within the Mainland – especially with regard to ShanXi, Guangzhou and Beijing?

Methods

Sample

Within China: Three separate regions provide a range of geo-engineering experience and per capita income in secondary schools (Beijing, Guangzhou, ShanXi). Government-funded secondary school types are all-through secondary, junior and senior secondary and, to a lesser extent, vocational schools. Schools by region included: Beijing - two junior secondary, two senior secondary, one vocational; Guangzhou – two all-through secondary; and ShanXi – one junior secondary, one senior secondary, one vocational. Schools were approached opportunistically via their engagement with teacher education programmes associated with Beijing Normal and South China Normal Universities. The sample information included: 2241 questionnaires from male and female students distributed/collected (Beijing, 1153 questionnaires (male: 662; female: 462; undisclosed: 29); Guangzhou, 407 questionnaires (male: 186; female: 220; undisclosed: 1); ShanXi, 681 questionnaires (male: 318; female: 353; undisclosed: 10)); Year of study (Forms 1/2: 622 students; Forms 3/4: 1315 students; and Forms 5/6: 301 students); Type of school attended (Grammar and Vocational); Parental experience of engineering; and Ethnic background (95+% self-identified as Han). Given the homogeneity of this part of the sample, ethnicity was not used to differentiate between student responses (see Table 1).

TABLE 1 ABOUT HERE

HK: This larger sample was selected to be representative of government-funded secondary schools. It was proportionally stratified (age and sex of student, school type and district) with a randomized selection of schools and classes within each selected school. 23 government-funded schools participated; 3,724 students (male: 1648; female: 2032; 44 unreported). The sample did not include vocational schools as these have been phased out by the current government.

Each school principal and participant signed a consent form to indicate their active agreement to participate in the study. Parents of each student also provided consent.

Instrument

The survey questionnaire was adapted from the Education and High Growth Innovation project (EHGI, Good and Greenwald 2007) to focus on secondary school students' engineering education experience and aspirations to study/pursue a career in engineering. The questionnaire covered student demographics, curricular and extra-curricular engineering experience, (activity-based) learning experiences and engineering efficacy (see Table 2). Domain-specific aspects of engineering experience and efficacy were devised with regard to actual within-school and extra-curricular activities in which students could engage and efficacy was based on self-assessed competence in undertaking/completing engineering-related actions. Question groupings were assessed by tick boxes, frequencies, Likert and competence scales. The adapted questionnaire was originally validated (face and content) in Hong Kong (in both English and Traditional Chinese) with the Chinese version back-translated. The Mainland Chinese version was further validated in a (Guangzhou) pilot study and used in Beijing and ShanXi regions. Due to limitation in funding/ability to longitudinally follow-up students in post-secondary education/work, the questionnaire completion was a one-time opportunity within which engineering outcome identified students aspiration to become an engineer, an approach similar in method to Harding, Mayhew, Finelli & Carpenter (2007) and To, Lai, Lung & Lai (2014). Questionnaires were administered on a whole-class basis so as not to disrupt on-going lessons. Classes per school were randomly selected within Year of study.

Data management

An Exploratory Factor Analysis (EFA) was conducted on the Guangzhou pilot sample to examine the underlying factor structure, identify and differentiate between individual questions, ascertain whether item groups or an underlying singular engineering factor characterized the questionnaire and assess for reliability of factors (Worthington and Whittaker 2006). The EFA produced a Kaiser-Meyer-Olkin (KMO) of 0.890 (showing sampling adequacy for analysis) and Bartlett's Test for Sphericity (X^2[5671] = 22724.91,

$p<0.001$ - showing that the data were appropriate for factor analysis). The EFA used Varimax factor rotation with a minimum eigenvalue of 1.0 and showed a large number of factors related to the nine, logic-based item-groups (Table 2). With regard to each item grouping, reliability was established for factors loading above 0.5 and using "alpha-if-item-deleted" tests to ensure that only key contributing questions were included per item-group/factor. Reliability averaged for the nine item-groups was 0.83 (ranging from 0.63 to 0.95). Each factor and sub-factor reached satisfactory levels of reliability (McMillan and Schumacher 2001), with the exception of parental encouragement. After the EFA, reliability of the factors were assessed on the non-pilot China sample (1795 questionnaires); with an average item group reliability of 0.84 (range: 0.67 to 0.95). Two further reliability assessments were undertaken, one combining the pilot with the other Chinese geo-engineering regions (2201 questionnaires) and the other combining all Chinese regions with Hong Kong (5925 questionnaires). Average reliability for all Chinese regions was 0.86 (range 0.66 to 0.95) and the combination of China with Hong Kong was 0.85 (range 0.64 to 0.95).

TABLE 2 ABOUT HERE

Item-groups (factors and sub-factors) were divided into Outcome and Experiential/attitudinal factors. Outcome expressed the aspiration become an engineer. Eight Experiential/attitudinal factors with four Sub-factors were structured from questionnaire groupings concerning engineering-oriented attitudes, motivations, activities and perceptions of engineers. Further analyses compared between regions supported by Scheffe post hoc analyses to ascertain significance of difference between regions. To ascertain relative contribution of the various factors to the outcome hierarchical regressions were undertaken in HK, the Mainland and within Mainland regions. While the use of regression as a method has been criticised (Whittingham, Stephens, Bradbury and Freckleton 2006), it is a technique that allows prioritisation of causal explanations associated with aspirations to become an engineer. Ordering of regression variables initially partialled-out demographic from experiential/attitudinal variables, and variable hierarchy was based on a combination of literature and magnitude of means identified in our descriptive results. Tests for collinearlity (VIF) showed moderate to low levels within these regressions.

Results

Summary explanations of factors (see Table 3):

1. Practical (learning) activities related to STEM subjects: The factor's moderately high mean indicates these aspects were important for students. A sub-factor based on background in science and mathematics had a mid-level mean.

2. Participation in engineering related activities at school: The mean indicates that students rarely participated in these activities. Nearly half of the students (47%) did not participate in any within-school engineering activities), while a few students were very active (19%) participated in 5 or more activities.

3. Encouragement to participate by STEM teachers: The factor's moderately high mean indicates that these teachers, especially in mathematics, encouraged students to do well in their STEM subjects.

4. Encouragement to participate in STEM activities by parents: The mean indicates moderately high encouragement in educational achievement.

5. Extracurricular engineering activities: The moderately low mean indicates infrequent engagement in these activities (clubs, meeting engineers, etc.). This hands-on engagement formed the basis of the Build/take apart/explain (BTE) sub-factor.

6. Motivation to engage in school-based engineering activities: The moderate mean suggests that students did not receive much stimulation in this range of activities.

7. Perceptions of engineers/engineering: The relatively high mean indicates a strong positive view of engineers. Perceptions also showed that engineers were unlikely to be women or come from an ethnic minority. Presentation of engineers sub-factor was also found was found with a mid-level mean.

8. Engineering efficacy: Given efficacy/confidence could range from 0 to 100%, the mean indicates only a moderate level of confidence in undertaking these tasks.

9. The outcome factor was composed of two items ('I really want to be an engineer' and 'I want to know more about engineering'): The mid-level mean indicated that, generally, students were not very interested/nor expected to become an engineer.

TABLE 3 ABOUT HERE

Table 4 factor correlations identified: a) strong correlations between the Outcome factor and Motivation, Practical activities and Extracurricular (engineering) activities; b) Adult encouragement had a consistent and strong effect on other factors; c) Engineering efficacy was a strongly related to most factors; but d) School-based engineering activity had the lowest level of correlation related to all other factors.

TABLE 4 ABOUT HERE

Mainland demographic differences (research question 1)

Four main demographic variables were assessed for differences with regard to each of the experiential/attitudinal and outcome variables (see Table 5):

Relative as engineer results favoured students with engineering relatives. Experiential/attitudinal and outcome factors were significantly higher for students with engineering relatives – except for Engineering activities in school and Social motivation. These differences were consistent for sub-factors Knowledge about engineering, BTE and Mathematics efficacy.

Age results point to periods in students' lives when aspects of engineering were most important. The youngest age group scored highest for Encouragement by teacher, Engineering efficacy and Mathematics efficacy. The mid-age group received most Encouragement by parent and engaged in Extracurricular involvement. The oldest age group scored highest for BTE sub-factor, Motivation and engagement in Engineering activities in school, Perception of engineers and Aspiration to become an engineer.

Sex results show males more likely to participate in engineering activities than girls with regard to: Practical (learning) activities, Knowledge about engineering, Extracurricular engineering activities, BTE, Motivation to engage in engineering activities and Outcome. With the exception of Practical (learning) activities, none of the means were high. There were no significant differences with regard to Engineering activities in school, Encouragement by teacher, Encouragement by parents, Social motivation, Perception of engineers and, most strikingly, General engineering efficacy.

School type results showed consistently high levels of attitude and efficacy favouring grammar schools (analysis undertaken for Beijing and ShanXi only). There was only a small difference between schools for Engineering activities in school, and no difference for Extracurricular engineering activities, BTE, Social motivation or Aspiration to become an engineer.

TABLE 5 ABOUT HERE

Hierarchical linear regressions were undertaken to prioritise which experiential/attitudinal factors contributed significant variance regarding students' aspirational decisions (Table 6a). With demographic factors initially partialled-out, 44.1% of variance was contributed by experiential/attitudinal factors. Only a further 4.1% of variance was contributed by demographic factors. Table 6a identifies that initial demographic factors of an Engineer in the family, Age of student and Sex were each significant. The combined demographic and experiential/attitudinal only found significance for Age and a hierarchy of: Motivation to engage in engineering activities, Practical learning activities, Encouragement by parents, Extracurricular engineering activities and Engineering activities in school. Encouragement by teachers, Perceptions of engineers and Engineering efficacy did not offer significant contributions of variance to student Aspirations.

TABLE 6 ABOUT HERE

Differences between the Mainland and HK (research question 2)

While the Mainland and HK share common statehood, in an engineering/economic sense China is described as an industrialising country while HK is a highly advanced post-industrial society. In our comparisons Mainland students had higher scores for virtually of the Experiential/attitudinal and Outcome factors (see Table 3). With regard to the particular factors:

1. Practical (learning) activities were more highly rated in the Mainland than HK and this characterised each of the individual questions; they showed greater Knowledge about engineering (sub-factor).
2. Participation in engineering related activities at school showed higher levels of engagement in the Mainland than HK, especially regarding: 'Visit educational websites related to engineering', 'Participate in competitions related to engineering or computers', and 'Participate in engineering or computer societies'.
3. Encouragement by teachers did not show significant differences between the Mainland and HK.
4. Encouragement by parents was significantly stronger in the Mainland.
5. Extracurricular engineering activities did not show high levels of engagement in either Mainland or HK, but Mainland students were significantly more likely to be engaged in these activities and the BTE sub-factor.
6. Motivation to engage in school-based engineering activities and the Social motivation sub-factor were significantly higher in the Mainland. There were no peer-support differences between Mainland and HK.
7. Perceptions of engineers/engineering were rated significantly higher in Mainland with the exception of 'Has a degree', 'Is female' and 'Comes from an ethnic minority'.
8. Engineering efficacy showed Mainland students felt significantly more confident in engineering activities across all items (by an average of 5%). Learning of mathematics sub-factor was also significantly higher for Chinese students.
9. The outcome factor was rated significantly higher for Mainland students

Given the consistent factor differences between Mainland and HK, a separate hierarchical regression was undertaken for HK so that contributory factors to students' aspirations could be compared with the Mainland (Table 6b). This regression initially partialled-out demographic factors. Experiential/attitudinal factors contributed 45.6% of variance to student aspirations and demographic factors contributed a further 4.8%. In HK, the demographic analysis identified Sex (males) of student, Engineer in the family and Age each contributed significantly. The combined demographic and attitude/experience factors reinforced Sex and Age of students with a hierarchical order of variance dominated by: Motivation to engage in engineering activities (similar to the Mainland); Extracurricular engineering activities; Practical learning activities; Perception of engineers; negative variance for Encouragement by teacher; and Engineering efficacy. HK did not identify within-school engineering activities or Encouragement by parent as making a significant contribution to student Aspirations. In both regions, the demographic factor of Age made a significant contribution, but only in HK did sex (males in particular) make a further significant contribution.

TABLE 7 ABOUT HERE

Differences between regions within Mainland China (research question 3)

The Mainland sample included three different geo-engineering regions: Beijing, ShanXi, and Guangzhou. As presented in Table 3, differences between regions identify that students in Beijing had generally higher scores than the other regions although Guangzhou had the highest Outcome score. More specifically, students in all regions had similar engagement in Practical (learning) activities; this non-significant difference hides the more specific finding that Beijing had the highest individual question scores except for ‘I want to do engineering subjects after secondary school’ where Guangzhou students scored highest. Students in Guangzhou had the highest Engineering activities in school and ShanXi students had the least. Students identified that Guangzhou teachers provided the highest levels of Encouragement with ShanXi providing the lowest levels; this was consistent among all types of teacher (science, mathematics, D/T). Encouragement by parent was strongest in Beijing and weakest in ShanXi; although all parents provided strong support for their children’s education. Beijing provided the strongest encouragement for science education and Guangzhou parents provided the strongest encouragement for engineering education. Beijing students were more engaged in extracurricular engineering activities. The greater extracurricular involvement by Beijing students was particularly seen in the BTE sub-factor. Guangzhou students had slightly higher Motivation to engage in engineering levels than Beijing or ShanXi students – with Guangzhou students showing more curiosity about what engineers do and how they do it.

Beijing students showed higher Social motivation (sub-factor) with their scores encouraged by peers and teachers. All students, though, maintained neutral feelings with regard to ‘It will help me do well in my exams’. Guangzhou students had a more positive Perception of engineers than other regions, and this characterised most of the individual questions. ShanXi students, though, had higher levels of perception that engineers worked in offices and wore suits (Work conditions sub-factor). Beijing students showed the highest level of General engineering efficacy and this characterised most of the individual questions. Beijing students also scored highest on the Mathematics efficacy sub-factor as well as individual questions concerned with working with others (similar to the Social motivation sub-factor finding). An explanation of differences between Experiential/attitudinal factor findings among these regions appears to tell two stories: 1) that Beijing students generally had more access to practical, extracurricular and social activities related to engineering as well as parental encouragement and these experiences may have promoted their higher level of engineering efficacy; but 2) Guangzhou students had more access to engineering activities in school and encouragement by teachers, and this was associated with higher perceptions of engineers and motivation to engage in engineering activities. The Outcome factor results shows that the Guangzhou students had slightly higher Aspirations to become an engineer than Beijing students and both of these regions had significantly higher Aspirations than students in ShanXi.

Discussion and Conclusion

The need to maintain and further develop the engineering pipeline from secondary school to university and technical careers has been recognised universally if a country is to develop in the twenty-first century (Borrego and Bernhard 2011; King 2008; Sohn and Ju 2010). It is important to focus on secondary school students as they represent the age group in which engineering experiences are likely to affect their aspirations for further study/careers (Osborne and Archer 2007). Yet, simply asking secondary school students whether they wish to pursue studies/careers in engineering provides little insight into elements of the engineering pipeline. Recent studies have identified the importance of authentic experiences, attitudes, perceptions and efficacy that may affect the aspiration to become an engineer (Borrego and Bernhard 2011; Katehi et al. 2009; Lucas et al. 2009) as well as cultural, industrialising and social contexts (Sjøberg et al. 2005; Wei 2005); yet few international studies include China and its regions. In comparing between geo-engineering regions, our research questions provide insight into effects across the secondary school age range and diverse aspects of students' attitudes, authentic experiences, perceptions and efficacy regarding further study of/careers in engineering.

Focusing initially on demographic explanations for Mainland students, results only partially confirm the international literature. Sex differences showed boys had higher levels of knowledge and more positive attitudes regarding engineering, and this parallels Borrego & Bernhard (2011), Brophy et al. (2008) and Unfried et al. (2014). But, a lack of sex difference regarding engineering efficacy, encouragement from teachers/parents/peers, perceptions of engineers and within-school engineering activities may indicate a non-gendered Mainland approach to the curriculum integrates mathematics, science and technology courses for all students (Gao 2013; Wei and Thomas 2007). Age differences in attitudes and experiences supported the international literature showing that younger students had more positive attitudes and career aspirations regarding engineering (Capobianco et al. 2012; Wang and Degol 2013). Yet, students in the middle years of secondary schooling were offered/took-up more engineering activities and received more encouragement/support from their teachers. Effects of these enhanced engineering experiences may be seen to affect more positive perceptions and attitudes towards engineering aspirations among the oldest students – contradicting the international literature (Osborne and Archer 2007). Type of school attended affected all aspects of attitudes, experiences, efficacy and aspirations regarding engineers and engineering. Across the Mainland, it was the grammar as opposed to vocational schools that had the most positive views of engineers – this finding may contradict the expectation that vocational schools should provide focused STEM experiences for students (Watters and Christensen 2013). Finally, students with close relatives who work as an engineer had more positive attitudes, experiences, higher perceptions and efficacy regarding engineering (ASPIRES 2013; Devine 2004). From this initial review, we speculate that aspects of home, school type and gender may combine into an Engineering Capital that supports the aspiration for further study/careers in engineering.

Industrialising/post-industrial differences showed Mainland students to have more positive views of engineers than HK students. This difference bears strong resemblance to the international literature (Wei 2005; Sjøberg and Schreiner 2005) although we identify that industrialising/post-industrial differences can be found within a single country also. Comparisons showed that motivation to engage in engineering provided most of the variance in students' aspiration to become an engineer in both regions. The role of parents was important for Mainland students, as identified in the international literature (ETB 2005;

Godwin et al. 2014) and in descriptions of Chinese CHC (Biggs 1996). Parents contributed very little to HK student's aspirations – suggesting that CHC may be related to specific sub-cultures within Chinese society. HK students had a stronger reliance of facilities provided around the school (extracurricular clubs, practical learning activities) than their Mainland counterparts – perhaps identifying differences between the range of engineering experiences and Engineering capital that can be offered within schools (Borrego and Bernhard 2011) in this post-industrial society. The role of engineering efficacy was significantly higher in the Mainland than HK, although this did not contribute a significant amount of variance to the aspiration to become an engineer in the Mainland. These comparisons begin to identify regional cultural differences: Engineering/STEM culture appears to have a stronger collective basis in schooling and parental support in the Mainland, while HK students are dependent on involvement in extracurricular activities, personal perceptions of engineers and engineering efficacy.

Mainland comparisons show geo-engineering regional differences that relate to regional engineering needs and advancement towards post-industrialisation. Given that all Mainland schools provide a strong science, mathematics, technology and experiential backgrounds for students, it was not surprising to see high levels of practical (hands-on) learning activities taking place in all regions. Beijing and Guangzhou offered higher levels of extracurricular engineering activities, within school engineering activities and parental support than ShanXi - suggesting lower levels of industrialisation and exposure to a broad range of modern engineering activities in ShanXi. Guangzhou students received the highest levels of teacher encouragement, within-school engineering activities and had more positive perceptions of engineers, attitudes towards engineering, and aspirations to become an engineer. Beijing students, with higher levels of parental support and extracurricular engineering activities, appeared to have more (non-school based) engineering opportunities and this was associated with a higher level of engineering efficacy.

The differences found between these regions offer the opportunity to identify a range of new explanations for the perception and understanding of engineering within a large industrialising country. An initial explanation for geo-engineering differences within the Mainland identifies a trend that runs counter to the international (post-industrial) literature – that suggests lower levels of interest in engineering as a country becomes more industrialised (Wei 2005). It appears from our data that the more advanced industrial regions (moving away from heavy/mining engineering towards electronic and civil engineering) offer more engineering activity opportunities within and outside of schools. These opportunities are associated with more positive student perceptions of engineering and higher levels of aspiration to become an engineer. And, instead of the negative correlation between STEM interest and per capita earning proposed by Sjøberg and Schreiner (2005), this relationship may be better identified as an inverted 'U' where mid-levels of industrialisation offer the highest STEM aspirations among students. It seems obvious that schools and schooling processes can play a strong role in offering insight and support for the future development of engineers – especially where teachers and within-school engineering activities provide support and encouragement for students as found in Guangzhou. Both opportunities offered and encouragement provided support the need to develop a more sophisticated notion of Engineering/STEM Capital (ASPIRES 2013). This Capital, which appeared higher in both Beijing and Guangzhou than ShanXi, is likely to include elements of practical learning activities, motivation to engage in engineering opportunities, encouragement by parents and teacher, extracurricular opportunities and feelings of efficacy. These elements parallel science capital with regard to students' development of positive attitudes (and perceptions) of engineers, supported by family and teachers, and participation in extracurricular contexts. It should be noted, though, within-school engineering opportunities appear to play a limited role in the development of Engineering/STEM capital – this may be explained by the infrequent inclusion of engineering within the formal curriculum and, perhaps, limited understanding of engineering by teachers (Holman 2007).

Overall, this comparison of students' engineering experience and aspirations between industrialising and post-industrial regions of China offers a range of insight not previously found in the STM or engineering literature. There is a complex interplay of Experiential/attitudinal factors found within schools, supported by social relationships and culture which result in diverse presentations of engineering capital affecting student aspiration. Mainland Chinese students generally receive high levels of engineering support within their school curriculum/labour experience, teacher and parental support (affecting perceptions, attitudes and efficacy) although this varies within regional development. HK students tend to have less formal engineering experience, and their limited capital/lower levels of aspiration may be associated with low levels of parental support and the need to develop positive engineering attitudes/efficacy via extracurricular activities.

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Table 1: Breakdown of China Sample and Geo-engineering Region Sub-samples, based on demographic characteristics

Characteristics	*N* (questionnaires completed)	% (of Mainland sample)
REGION		
Beijing	1153	51.5
ShanXi	681	30.4
Guangzhou	407	18.2
INDIVIDUAL		
Sex:		
Male	1166	52.0
Female	1035	46.2
Unreported	40	1.8
Age		
12-13	622	27.8
14-15	1315	58.7
16-18	301	13.4
Unreported	3	0.1
SOCIAL		
Relative as engineer		
Father	174	7.8
Mother	54	2.4
Other close relative	471	21.0
Unreported or don’t know	1542	68.8
CULTURAL		
Ethnicity		
Chinese - Han	2150	95.9
Chinese – Zhuang	2	0.1
Chinese – Manchu	39	1.7
Chinese – Hui	24	1.1
Chinese – Mongol	7	0.3
Chinese – Other	10	0.4

Non-Chinese – Other	1	0.0
SCHOOL*		
Type:		
Grammar	1494	66.7
Vocational	340	15.2
Unreported	407	18.2

* Data was only collected on this characteristic for Beijing and ShanXi

Table 2: Item–groups for Experiential/attitudinal and Outcome Factors with descriptions and measures of reliability (*italics indicate sub-factors related to main group factors*): measurement, Exploratory Factor Analyses and Confirmation of Reliability

Experiential/attitudinal factors with question examples	How measured	EFA			Reliability across samples		
		Post "alpha-if-item-deleted" questions included	Eigenvalue (Proportion of variance)	Cronbach α	Sample w/o pilot Cronbach α	Sample with pilot Cronbach α	Include HK Cronbach α
Practical (learning) activities related to STEM subjects Ex: I enjoy learning; I enjoy taking things apart to see how they work	6-pt scales (strongly agree – strongly disagree)	10 questions	4.71 (31.36)	0.85	0.86	0.86	0.88
Sub-factor: Knowledge about engineering sub-factor *Ex: I understand what engineers do in industry; I understand how engineers use maths and science*		*2 questions*	*1.70 (11.36)*	*0.82*	*0.84*	*0.84*	*0.83*
Participation in engineering related activities at school Ex: Attend seminars conducted by engineers; Participate in competitions related to engineering	2-pt scales (participation – non-participation	6 questions	2.16 (35.97)	0.63	0.70	0.90	0.88
Encouragement to participate by STEM teachers Ex: My science teacher encourages me to do well; My D&T teacher encourages me to do well	6-pt scales (strongly agree – strongly disagree)	3 questions	2.33 (58.24)	0.85	0.82	0.82	0.64

Encouragement to participate in STEM activities by parents Ex: My parents know a lot about science; My parents think engineering is a good career	6-pt scales (strongly agree – strongly disagree)	4 questions	2.14 (42.86)	0.67	0.66	0.66	0.70
Extracurricular engineering activities Ex: Attend engineering club at school; Fixed something that was broken at home	6-pt scales (participate very frequently – no participation)	19 questions	10.62 (53.10)	0.95	0.95	0.95	0.95
Sub-factor: BTE (Build/Take apart/Explain) sub-factor *Ex: Explained how something I built works; Taken something apart to see how it works*		*4 questions*	*1.90 (9.48)*	*0.95*	*0.84*	*0.83*	*0.84*
Motivation to engage in school-based engineering activities Ex: I like making things; I like to experiment with things	6-pt scales (strongly agree – strongly disagree)	7 questions	4.63 (38.57)	0.86	0.86	0.86	0.88
Sub-factor: Social encouragement		*2 questions*	*1.56 (12.99)*	*0.72*	*0.74*	*0.74*	*0.71*
Perceptions of engineers/engineering Ex: Creative; Is an original thinker; Can help solve environmental problems	6-pt scales (very likely – very unlikely)	16 questions	7.07 (30.72)	0.90	0.89	0.89	0.90
Sub-factor: Work conditions *Ex: Works in an office; Wears a suit*		*2 questions*	2.33 (10.15)	*0.67*	*0.67*	*0.67*	*0.66*
General engineering efficacy Ex: Design a good website for my school; Use maths to help plan and build something; Explain why we recycle paper	10-pt confidence levels (0 – 100%)	22 questions	9.53 (45.24)	0.94	0.95	0.95	0.95

Sub-factor 1: Mathematics learning *Ex: Top grade in mathematics; Learn algebra/geometry*		*3 questions*	*1.87 (8.51)*	*0.87*	*0.77*	*0.89*	*0.89*
OUTCOME FACTOR **Aspiration to become an engineer**	6-pt scales (very likely – very unlikely)	2 questions	1.65 (82.64)	0.79	0.84	0.83	0.84

Table 3: General Means for Experiential/attitudinal and Outcomes Factors; Comparisons between Chinese regions and China/Hong Kong

Experiential/attitudinal factors	General mean (China)	Chinese regions				China/Hong Kong		
		Beijing	ShanXi	Guangzhou	F	China	Hong Kong	F
Practical (learning) activities	4.27	4.37	4.08	4.27	NS	4.27	3.84	353.77***
Knowledge about engineering	*3.16*	*3.30*	*2.96*	*3.12*	*11.71****	*3.16*	*2.92*	*49.09****
Engineering activities in school	0.29	0.18	0.09	0.92	2356.12***	0.29	0.25	11.51***
Encouragement by teacher	4.05	4.17	3.65	4.49	39.70***	4.05	4.04	NS
Encouragement by parent	4.32	4.41	4.16	4.32	14.94***	4.32	3.76	497.37***
Extracurricular engineering activities	2.40	2.67	2.13	2.20	32.46***	2.40	1.90	285.89***
BTE (Build/Take apart/Explain)	*3.44*	*3.61*	*3.18*	*3.38*	*20.92**	*3.44*	*2.82*	*341.39****
Motivation to engage in engineering activities	3.71	3.74	3.59	3.78	4.78**	3.71	3.29	203.86***
Social motivation	*3.64*	*3.72*	*3.54*	*3.55*	*4.06**	*3.64*	*3.45*	*29.42***
Perception of engineers	4.47	4.45	4.41	4.63	8.31***	4.47	4.04	365.16***
Presentation of engineers	*3.25*	*3.21*	*3.29*	*3.24*	*NS*	*3.25*	*3.24*	*NS*
General engineering efficacy	58.71	61.49	54.99	57.10	19.41***	58.71	52.49	126.17***
Mathematics efficacy	*63.05*	*65.95*	*57.33*	*64.30*	*21.79****	*63.05*	*55.70*	*106.82****
Outcome	3.23	3.29	3.03	3.42	9.59***	3.23	2.85	95.96***

*: $p<0.05$; **: $p<0.01$; ***: $p<0.001$

Table 4: Correlation Matrix for Main Experiential/attitudinal and Outcome Factors (China only)

	1	2	3	4	5	6	7	8	9
1. Practical (learning) activities related to STEM subjects	1.0	-.116**	.426**	.533**	.523**	.544**	.388**	.533**	.489**
2. Participation in engineering related activities in school		1.0	.196**	.094**	.102**	.104**	.153*	.057*	.142**
3. Encouragement to participate by teachers			1.0	.364**	.375**	.305**	.231**	.353**	.323**
4. Encouragement to participate by parents				1.0	.506**	.474**	.414**	.391**	.454**
5. Extra-curricular engineering activities					1.0	.509**	.291**	.427**	482**
6. Motivation to engage in school-based engineering activities						1.0	.530**	.495**	.665**
7. Perceptions of engineers/engineering							1.0	.386**	.402**
8. General engineering efficacy								1.0	.395**
9. Outcome: Aspiration to become an engineer									1.0

*: p<0.05; **: p<0.01

Table 5: Within China Demographic Comparisons of Means for Experiential/attitudinal and Outcomes Factors (general mean for each factor in Table 3)

	Personal characteristics										School Type+		
	Sex			Age				Relative as engineer					
EXPERIENTIAL/ATTITUDINAL FACTORS	Male	Female	F	S2	S4	S6	F	Yes	No	F	Grammar	Vocational	F
Practical (learning) activities	4.39	4.13	49.00***	4.33	4.27	4.20	2.60	4.54	4.18	69.62***	4.34	3.94	54.94***
Knowledge about engineering	*3.27*	*3.04*	*13.26****	*3.26*	*3.13*	*3.11*	*1.70*	*3.67*	*2.98*	*84.80****	*3.22*	*2.96*	*8.06***
Engineering activities in school	0.28	0.30	0.69	0.25	0.21	1.29	280.63***	0.33	0.30	1.63	0.14	0.15	5.37*
Encouragement by teacher	4.10	4.00	2.02	4.38	3.91	4.12	19.32***	4.28	3.99	11.66***	4.10	3.41	52.01***
Encouragement by parent	4.33	4.30	0.64	4.21	4.39	4.22	9.60***	4.66	4.19	91.42***	4.36	4.13	16.09**
Extracurricular engineering activities	2.55	2.23	26.59***	2.27	2.48	2.37	3.78*	2.79	2.24	56.17***	2.49	2.55	0.33
BTE (Build/Take apart/Explain)	*3.71*	*3.13*	*106.26****	*3.32*	*3.46*	*3.54*	*3.42**	*3.77*	*3.32*	*40.82****	*3.47*	*3.35*	*2.16*
Motivation to engage in engineering activities	3.82	3.58	25.82***	3.58	3.73	3.83	5.76**	3.93	3.63	27.19***	3.73	3.51	9.34**
Social	*3.65*	*3.63*	*0.04*	*3.58*	*3.66*	*3.68*	*0.74*	*3.70*	*3.62*	*1.13*	*3.63*	*3.76*	*1.90*

motivation													
Perception of engineers	4.45	4.50	1.99	4.33	4.52	4.54	9.41***	4.61	4.45	11.68***	4.46	4.30	7.66**
Presentation of engineers	*3.23*	*3.26*	*0.63*	*3.10*	*3.29*	*3.36*	*9.76****	*3.16*	*3.27*	*4.62**	*3.19*	*3.49*	*24.68****
General engineering efficacy	59.33	58.10	1.67	59.73	59.12	55.08	5.09**	65.12	56.49	59.69***	61.48	48.29	95.08***
Mathematics efficacy	*63.81*	*62.21*	*1.88*	*67.34*	*62.78*	*55.54*	*19.17****	*69.36*	*60.46*	*40.89****	*67.06*	*43.44*	*217.08****
OUTCOME	3.41	3.04	31.80***	2.79	3.30	3.49	14.24***	3.59	3.10	37.96***	3.21	3.12	0.93

+: Data for this variable was not collected in Guangzhou

*: p<0.05; **: p<0.01; ***: p<0.001

Table 6a and b: Hierarchical regressions relating Experiential/attitudinal and Demographic variables with engineering outcome in China and Hong Kong

Coefficients

Model	China Factors					Hong Kong Factors				
		B	St. Error	Beta	t		B	St. Error	Beta	t
1	Constant	3.17	0.25		12.95***	Constant	3.40	0.13		26.83***
Demographic	Engineer in family	0.04	0.09	0.16	4.67***	Engineer in family	0.29	0.06	0.12	4.99***
	Age	0.22	0.08	0.10	2.77**	Age	0.11	0.04	0.06	2.56**
	Sex	-0.29	0.10	-0.09	-2.71**	Sex	-0.49	0.06	-0.18	-7.84***
2	Constant	-2.04	0.25		-6.07***	Constant	-0.97	0.19		-4.75***
Experiential/	Engineer in family	0.58	0.07	0.02	0.88	Engineer in family	0.03	0.04	0.01	0.60
attitudinal	Age	0.15	0.06	0.07	2.43*	Age	0.14	0.03	0.08	4.45***
&	Sex	0.01	0.09	0.00	0.09	Sex	-0.15	0.05	-0.06	-3.16**
Demographic	Eng Efficacy	0.00	0.00	-0.01	-0.15	Eng Efficacy	0.03	0.00	0.04	1.98*
	Perception of Eng	-0.07	0.06	0.04	1.32	Perception of Eng	0.10	0.03	0.06	2.89**
	Practical learning	0.28	0.08	0.14	3.69***	Practical learning	0.14	0.05	0.08	3.08**
	Teacher encourage	-0.07	0.03	-0.06	-1.96*	Teacher encourage	-0.08	0.03	-0.06	-2.69**
	Parent encourage	0.20	0.05	0.13	3.86***	Parent encourage	0.05	0.03	0.03	1.50
	Motivation to eng	0.62	0.05	0.44	12.27***	Motivation to eng	0.72	0.03	0.54	22.44***
	In-school eng activity	0.21	0.10	0.06	2.03*	In-school eng activity	-0.08	0.06	-0.02	1.20
	Extracurricular eng activity	0.17	0.05	0.12	3.52***	Extracurricular eng activity	0.19	0.03	0.12	5.89***

*: p<0.05; **: p<0.01; ***: p<0.001